

## Lessons Learned from Two Years of On-Orbit Global Positioning System Experience on International Space Station

Susan F. Gomez – NASA Johnson Space Center  
Michael L. Lammers – NASA Johnson Space Center

The Global Positioning System Subsystem (GPS) for International Space Station (ISS) was activated April 12, 2002 following the installation of the S0 truss segment that included the GPS antennas on Shuttle mission STS-110. The ISS GPS receiver became the primary source for position, velocity, and attitude information for ISS two days after activation. The GPS receiver also provides a time reference for manual control of ISS time, and will be used for automatic time updates after problems are resolved with the output from the receiver. After two years of on-orbit experience, the GPS continues to be used as the primary navigation source for ISS; however, enough problems have surfaced that the firmware in the GPS attitude code has had to be totally rewritten and new algorithms developed, the firmware that processed the time output from the GPS receiver had to be rewritten, while the GPS navigation code has had minor revisions. The factors contributing to the delivery of a GPS receiver for use on ISS that requires extensive operator intervention to function are discussed. Observations from two years worth of GPS solutions will also be discussed. The technical solutions to the anomalous GPS receiver behavior will be discussed.

The GPS receiver for ISS is a Space Integrated GPS/Inertial Navigation System (SIGI), manufactured by Honeywell (HI). The GPS receiver within the SIGI is a Trimble Navigation Force 19. The navigation code within the Force 19 was written by Trimble and the attitude code within the Force 19 was written by the National Aeronautics and Space Administration (NASA). The NASA code was derived from Trimble Navigation legacy code. The SIGI also contains a System Processor with code written by HI to output the GPS receiver messages in the proper protocol required for ISS and includes the code that outputs the GPS receiver time. The SIGI was procured as a Commercial Off the Shelf item. The following are the lessons learned from the development phase of the SIGI that contributed to the delivery of a product that is now requiring an extensive code rewrite in order to meet expectations.

Purchasing a Commercial Off the Shelf (COTS) product when the vendor does not have both hardware and software processes in place to ensure quality can lead to a poor quality product.

The philosophy of extensive testing of the software will not change the fact that the software is poorly designed.

Unrealistic schedules also contributed to the delivery of a product that did not meet expectation. Because the SIGI was incorrectly viewed as essentially a COTS procurement and not the development effort it really was, the project schedules were optimistic. The unrealistic schedules led to decisions to use as much existing code as possible. In hind sight, the attitude determination code should have been written completely new to meet ISS needs, rather than trying to use legacy code developed for use on aircraft. Specifically, the attitude determination code uses a search technique to

solve for integers. This method suspends all output from the receiver while the search method searches thru the range of integers. This causes frequent gaps in the position and velocity updates. These problems, plus additional problems with the attitude code discussed below, caused NASA and to replace the existing integer resolution method with a new method.

The following are the problems encountered using the GPS after delivery was already made to the ISS program.

It was discovered that the time output did not propagate well when the SIGI was tracking less than 4 satellites. Additional problems were found when the HI code would jump entire GPS epochs when the navigation processor would reset itself. ISS was intending to use the time from SIGI as ISS time. The work around established was for operators to manually control the clock drift rate of the flight computers using error between onboard computed GPS time or ground computed GPS time and ISS clock time. This was an unanticipated burden on the operators. The time code has been rewritten. Plots are shown comparing the time output from SIGI prior and after the code rewrite.

Several problems surfaced in the attitude determination code. On two occasions, the code output a IEEE 754 Not-A-Number. This caused both the primary and backup ISS guidance and navigation computers to stop processing. Attitude control was handed off from the US side to the Russian side, resulting in loss of micro-gravity and use of propellant supplies for control. High rate communications antennas were pointed manually by the ground during the several hours required to re-boot the US computers. The attitude determination code also resets itself under certain circumstances which were not seen prior to flight. When the code resets itself, it erases all of its memory and needs re-initialization. This was another unanticipated burden on the operators. These problems caused NASA to pursue re-writing the attitude determination code using a code standard. Plots are shown comparing the attitude output from SIGI prior and after the code rewrite.

The problems in the navigation code were more subtle. The GPS receiver was tracking satellites through the Earth's atmosphere which caused significant navigation errors. The health messages from the GPS receiver were out of sync with the actual navigation message, causing ISS to use solutions that it should have screened. The ionosphere was also causing significant errors that were not anticipated. Plots are shown comparing the navigation output from SIGI prior and after the code rewrite. The problems caused by the ionosphere have not yet been solved.

In conclusion, the code residing in the GPS receiver for ISS is equally as complicated as the code residing in the ISS flight computers. The code within the GPS receiver should have been developed with the same rigor as the code residing in the flight computers that was developed to the specification of a man rated space vehicle. Since the GPS receiver code was not written to such a specification, it had to be rewritten.